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Novel GaAs/GaSb heterostructures emitting at 2 μm wavelength

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Abstract. We report on growth as well as optical, transmission electron microscopy and X-ray diffraction studies of a new type of a GaAs/GaSb heterostructure, with 1 to 3 monolayer thick GaAs layers embedded within unstrained GaSb. In such structures the GaAs layer is under tensile stress, in contrast to the situation in which self-organized growth of quantum dots is commonly observed. The structure emits light in the 2 μm wavelength range.

Quantum dots (QDs) have recently attracted considerable interest due to their rich physics and optoelectronic applications, especially in prospective lasers [1]. Up to date, a number of the lattice mismatched semiconductor systems including InAs/GaAs [2], (Ga,In,Al)Sb/GaAs [3, 4], InAs/InP [5] and InP/InGaP [6] were found to form self-organized QDs under appropriate conditions. Most of the papers concern the situation when a thin strained layer is inserted in a matrix of an unstrained wider band-gap semiconductor with a smaller lattice constant. The quantum well (QW) and QD structures with different types of band offsets have been studied, including both type I [2, 5, 6] and type II [3, 4] band line-ups. The common feature of all these heterostructures is that the narrow band-gap material is under compressive strain. Furthermore, the surrounding matrix material is usually a relatively wide-gap compound such as GaAs or InP. As a result, the possible operating wavelength of such QD lasers is shorter than 1.55 μm. The potential advantage of type II QDs for the suppression of the Auger recombination channels make them particularly promising for light emission in the near- and mid-IR regions, particularly above 2 μm, where conventional types of semiconductor lasers meet severe problems due to Auger processes [7]. Thus, it is important to be able to extend the emission wavelength range of type II QD heterostructures beyond 2 μm.

In this paper we demonstrate a new type of a lattice-mismatched heterostructure characterized by intense photoluminescence (PL) in the spectral range of 1.7–2.3 μm at low temperatures. The samples contain ultrathin GaAs layers grown pseudomorphically in a GaSb matrix. The GaAs thickness was varied between 1 and 3 monolayers (MLs), i.e. within a typical range for the formation of self-organized QDs driven by a 7% lattice mismatch between GaAs and GaSb [3]. In contrast to the systems studied previously, the GaAs layer inserted into GaSb is under tensile stress and it can serve as a model for experimental studies of such systems, particularly that in the reversed structures (GaSb in GaAs) the self-organised QD formation is reasonably well documented [3, 4]. To the best of our knowledge, the only work concerned with the emission properties of comparable structures was reported recently by Glaser et al. [8], who observed a strong emission from AlAs monolayers in AlSb.

Both single GaAs/GaSb structures and a superlattice (SL) were grown by molecular beam epitaxy (MBE) on GaSb(001) substrates at a constant temperature of 520°C. Conventional solid source effusion cells were used to produce Ga, Al and As_4 fluxes, whereas Sb_2 flux was supplied from a RB-075-Sb cracking cell. The single structures contain a 0.5 μm thick GaSb buffer layer followed by a 0.3 μm GaSb layer with an ultrathin GaAs layer of varying thickness inserted in the center and confined by 30 nm $Al_{0.5}Ga_{0.5}As$ barriers on both sides. The GaAs layer is grown under (2×4)As-stabilized conditions with a 10 s growth interruption before and after to avoid As and Sb flux intermixing. The growth time of GaAs was varied between 2" and 5" in different samples, or between 1.2 and 3 MLs. Several samples were grown without substrate rotation to ensure a uniform variation of the GaAs thickness across the substrate surface. A ten-period 1.2 ML-GaAs/4 nm-GaSb SL sample was grown under the same conditions. The PL experiments were performed in a closed-cycle He cryostat or a liquid nitrogen cryostat, in the temperature range from 8 K to 300 K. CW laser diodes emitting either at 0.8 μm or at 1.3 μm were used for the PL excitation.

The SL structure was characterized by X-ray diffraction (XRD). Figure 1 shows a (004) $\theta - 2\theta$ XRD rocking curve measured in the SL sample. Both a zero-order SL reflection and higher-order satellites are prominent, providing an estimate of the SL period of 4.3 nm and nominal thickness of GaAs layers within the SL of 1.2 ML, in good agreement with design specifications. The simulations of the SL XRD rocking curves (Fig. 1) yield an estimate of the average broadening of the layers along the growth direction, resulting e.g. from the effects of inter-diffusion and Sb segregation during MBE growth [9]. This effect is observed through a fast decrease of the relative intensities of the SL satellites with the satellite order. The broadening of the GaAs layers in our sample is 4–5 ML. In such case the formation of ideal abrupt GaAs quantum wells can be ruled out, as well as the formation of a dense array of thick 3-dimensional (3D) QDs. Rather, the XRD data describe a SL built from GaAsSb layers, with spatial nonuniformities due to the nanoscale alloy composition or thickness fluctuations.

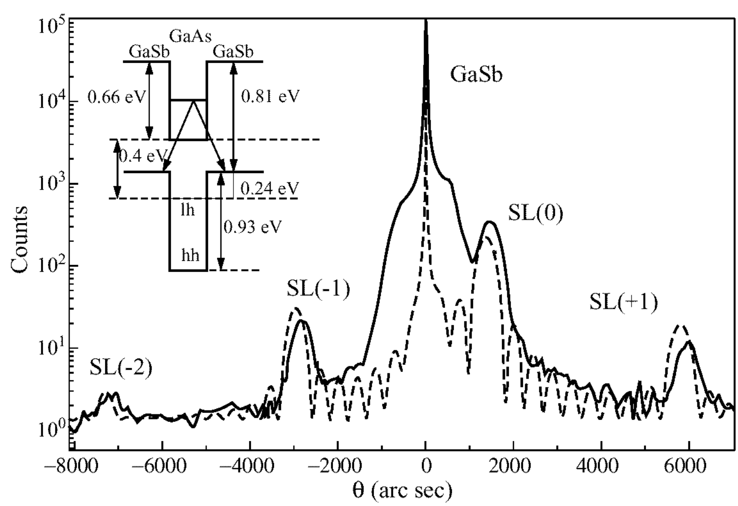

Fig. 1. XRD $\theta-2\theta$ rocking curves for the SL sample: experimental (solid curve) and simulated using with a Gaussian-like broadened distribution of As atoms up to 4.5 ML FWHM (dashed curve). The inset shows the schematic diagram of band line-ups and optical transitions for tensile strained GaAs in unstrained GaSb.

A set of the samples was studied by transmission electron microscopy (TEM) in cross-section geometry using a Philips EM-420 microscope at 100 kV. It is well known that (200) reflections are chemically-sensitive for face-centered cubic materials and can be used to detect the composition variation [10]. Figure 2 demonstrates the dark field (DF) images of single GaAs/GaSb samples with different GaAs thickness. All the images were obtained at the same conditions. It should be noted that GaAs insertions in all the images are seen as thin dark stripes, which are not continuous. The image of the 0.8 ML GaAs layer looks like a dotted line and consists of the dots with lateral sizes of about 1 nm (Fig. 2(a)). By raising the nominal thickness of GaAs, the TEM image shows dash line contrast and reveals the extended islands having noticeable strain field (Fig. 2(b)). These islands do not interlock themselves with the further increase in the GaAs thickness. But their sizes raise in the growth direction, that is seen in Fig. 2(c) as enlargement of dark haloes near the islands. In Fig. 2(d) one can see the extended defects near some islands, that demonstrates the starting of relaxation process in the structure with a 2 ML GaAs insertion.

The structures with thin GaAs layers exhibit PL at low temperatures. Figure 3 displays the PL spectra measured at 80 K at low excitation conditions (1 W/cm^2) in the single layer samples with varying GaAs thickness. All the spectra show a peak at $\sim$0.8 eV due to the band-to-band transitions in bulk GaSb, accompanied by a 0.775 eV peak attributed to donor - deep native acceptor recombination, and another peak, with the peak energy related to the GaAs thickness as deduced from the XRD measurements and extrapolating the GaAs deposition time. As the thickness increases from 1.2 to about 3.5 ML the peak shifts from 1.7 μm to 2.3 μm. Simultaneously, the peak undergoes some broadening, and its maximum intensity progressively decreases. The integrated intensity remains almost constant up to the nominal thickness of about 2.5–3 ML, and then it abruptly decreases in thicker layers. The emission wavelength of the GaAs/GaSb structures remains well below the GaSb band gap due to the type II band line-up. The inset in Fig. 1 demonstrates the expected band offsets and the scheme of optical transitions, as estimated using the van der

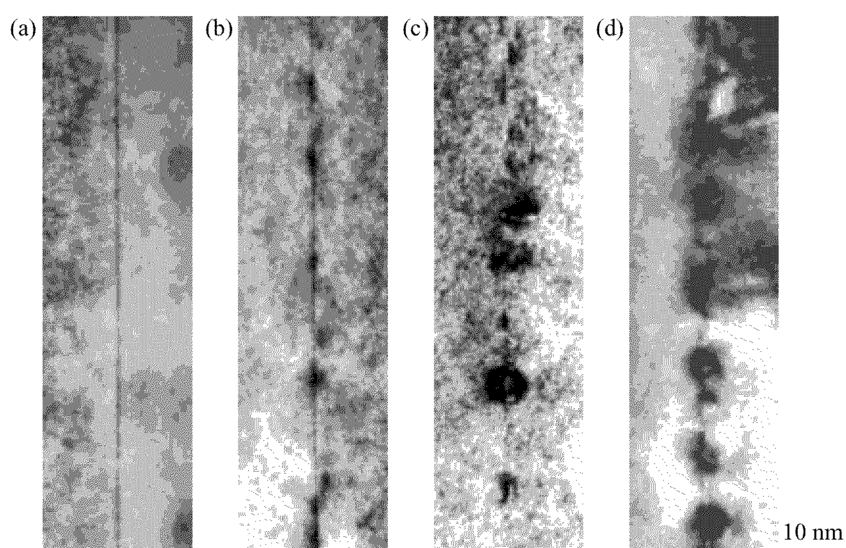

Fig. 2. Cross-section g[002] DF TEM images of the single-layer GaAs/GaSb samples with different nominal thicknesses of a GaAs layer: (a) 0.8 ML, (b) 1.2 ML, (c) 1.5 ML and (d) 2.0 ML.

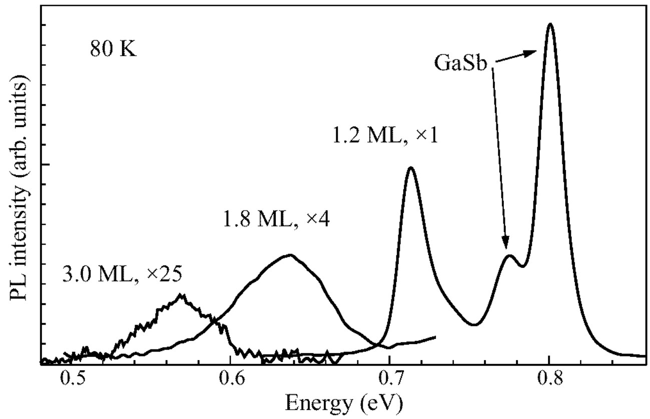

Fig. 3. Low excitation PL spectra of single-layer GaAs/GaSb samples with different GaAs nominal thicknesses.

Walle approach [11]. A strong biaxial stress induced by the 7% lattice mismatch results in a shrinkage of the GaAs band gap down to about 0.4 eV, making it noticeably smaller than the equilibrium band gap of the surrounding bulk GaSb. Nevertheless, the resulting band line-ups are of type II with electrons confined in GaAs and holes in GaSb.

In conclusion, we have presented an optical, TEM and XRD studies of a new type of heterostructure combining a thin layer of GaAs in GaSb, where GaAs is under tensile strain. The structure is characterized by a type II band offset and it emits bright PL in the spectral range of 1.7–2.3 μm, depending on the nominal thickness of the GaAs layers.

Acknowledgements

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References

[1] Y. Arakawa, H. Sakaki, *Appl. Phys. Lett.* **40**, 939 (1982).
[2] A. Madhukar, Q. Xie, P. Chen, A. Konkar, *Appl. Phys.Lett.* **64**, 2727 (1994).
[3] F. Hatami, N. N. Ledentsov, M. Grundmann, J. Bhrer, F. Heinrichsdorff, M. Beer, D. Bimberg, S. S. Ruvimov, P. Werner, U. Gsele, J. Heydenreich, U. Richter, S. V. Ivanov, B. Ya. Meltser, P. S. Kop'ev, Zh. I. Alferov, *Appl. Phys. Lett.* **67**, 656 (1995).
[4] E. R. Glaser, B. R. Bennett, B. V. Shanabrook, R. Magno, *Appl. Phys. Lett.* **68**, 3614 (1996).
[5] H. Marchand, P. Desjardins, S. Guillon, J. -E. Paultre, Z. Bougrioua, R. Y. -F. Yip, R. A. Masut, *Appl. Phys. Lett.* **71**, 527 (1997).
[6] N. Carlsson, W. Seifert, A. Petersson, P. Castrillo, M. E. Pistol, L. Samuelson, *Appl. Phys. Lett.* **65**, 3093 (1994).
[7] G. G. Zegrya, A. D. Andreev, *Appl. Phys. Lett.* **67**, 2681 (1995).
[8] E. R. Glaser, T. A. Kennedy, B. R. Bennett, B. V. Shanabrook, *Phys. Rev.* **B 59**, 2240 (1999).
[9] R. N. Kyutt, A. A. Toropov, S. V. Sorokin, T. V. Shubina, S. V. Ivanov, M. Karlsteen, M. Willander, *Appl. Phys. Lett.* **75**, 373 (1999).
[10] E. Bithnel, W. Stobbs, *Phil. Mag.* **A 60**, 39 (1989).
[11] C. G. van der Walle, *Phys. Rev.* **B 39**, 1871 (1989).